

## A2.2 Check and Reflect

For some of the following questions, you may use the periodic table or the table of polyatomic ions in Table E of Student Reference 12.

### Knowledge

- Define each of the following and provide an example of each:
  - ion
  - cation
  - anion
  - polyatomic ion
  - multivalent metal
- List the Greek prefixes corresponding to the numbers from 1 to 10.
- Write symbols or formulas for the following ions:
  - sodium ion
  - calcium ion
  - silver ion
  - copper(II) ion
  - lead(IV) ion
  - chloride
  - chlorate
  - chlorite
  - acetate
  - ammonium
- Name the following ions:
  - $\text{Al}^{3+}$
  - $\text{K}^+$
  - $\text{Zn}^{2+}$
  - $\text{Ni}^{3+}$
  - $\text{Fe}^{2+}$
  - $\text{Fe}^{3+}$
  - $\text{HCO}_3^-$
  - $\text{OH}^-$
  - $\text{SCN}^-$
  - $\text{SO}_3^{2-}$
- Name the following molecular compounds containing hydrogen:
  - $\text{CH}_4(g)$
  - $\text{NH}_3(g)$
  - $\text{H}_2\text{O}(l)$
  - $\text{H}_2\text{S}(g)$
  - $\text{HF}(g)$
- Classify the following compounds as molecular or ionic from their names or formulas:
  - $\text{CuCl}_{2(s)}$
  - $(\text{NH}_4)_2\text{S}(s)$
  - $\text{NH}_3(g)$
  - $\text{Fe}(\text{NO}_3)_3(s)$
  - $\text{CCl}_4(l)$
  - $\text{C}_6\text{H}_{12}\text{O}_6(s)$
  - sodium oxide
  - sulfur hexafluoride
  - methane
  - zinc sulfate
- What does IUPAC stand for?
  - Use an example to explain the need for the IUPAC system of naming chemical compounds.

### Applications

- Name the following ionic compounds:
  - $\text{AlCl}_{3(s)}$
  - $\text{CaS}(s)$
  - $\text{Na}_3\text{N}(s)$
  - $\text{K}_2\text{SO}_4(s)$
  - $\text{Li}_2\text{O}(s)$
  - $\text{FeI}_{3(s)}$
  - $\text{Pb}(\text{NO}_3)_4(s)$
  - $\text{Cu}_3\text{PO}_4(s)$
  - $\text{NH}_4\text{NO}_2(s)$
  - $\text{NaCH}_3\text{COO}(s)$
- Write the formulas of the following ionic compounds:
  - sodium hydroxide
  - ammonium sulfite
  - magnesium thiocyanate
  - calcium hydrogenphosphate
  - aluminium acetate
  - chromium(III) chloride
- Write the formulas for the following molecular compounds:
  - dinitrogen tetraoxide
  - phosphorus pentachloride
  - nitrogen triiodide
  - carbon monoxide
  - tetraphosphorus decaoxide
  - carbon disulfide
  - sulfur trioxide
  - methane
  - ammonia
  - sucrose
- Write the name of each of the following molecular compounds:
  - $\text{CBr}_4(g)$
  - $\text{NO}(g)$
  - $\text{OF}_2(g)$
  - $\text{IBr}(g)$
  - $\text{SeCl}_2(g)$
  - $\text{PCl}_3(g)$
  - $\text{N}_2\text{O}_3(g)$
  - $\text{SCL}_{2(g)}$

### Extension

- For each of the following, either write its name or the formula. Both ionic and molecular compounds are listed.
  - $\text{H}_2\text{O}_{2(l)}$
  - $\text{Fe}(\text{SCN})_3(s)$
  - ethanol
  - sodium silicate
  - ammonium perchlorate
  - $\text{SF}_6(g)$

## A 2.3 Properties and Classification of Ionic and Molecular Compounds

If someone calls you “the salt of the Earth,” you are receiving a compliment. Salt was precious in ancient times, especially in hot climates, where a good supply is essential for life. This type of salt is sodium chloride, but it is not the only kind of salt. Magnesium sulfate and lead(II) iodide are also salts—although they are not meant for the dinner table. Magnesium sulfate is a component in fertilizer, while lead(II) iodide was once used to make a bright yellow paint. Today its use is restricted to specialty artist’s paints. Each of these chemicals has its own properties. Sodium chloride is edible. Magnesium sulfate (also called Epsom salts) may be mixed with water and used for soaking tired, dry feet to make the skin feel soft. Lead(II) iodide is a poison.

These properties do not seem similar, yet these compounds have many properties in common. All of them melt above 800°C, which is much hotter than a candle flame, for example. They all form crystals. Their crystals have the interesting property that, if they are ground up and then examined under a microscope, the new tiny crystals look just like the bigger ones, with flat surfaces and well-defined edges. None of these solid compounds conduct electricity but all of their solutions do. All of these compounds are ionic: they are composed of positive ions and negative ions.

Many important compounds are not ionic. Water, methane, wax, caffeine, and glucose are all molecular compounds. At first look, they may not seem to have properties in common. Water is a liquid, while methane is a gas. The others are all solids. But they all melt below 250°C, a relatively low temperature. This temperature can easily be reached in a very hot frying pan. These five compounds are related in many other ways as well. None of them contain any metals. Also, none of them conducts electricity, and neither do the solutions of those that will dissolve in water. In this section, we will examine both ionic and molecular substances to see how their properties are determined.

### infoBIT

Both ionic and molecular compounds form crystals. Possibly the most important molecular crystal studied in the last century was DNA. DNA is the molecule responsible for passing genetic information from one generation to the next in all living things. An X-ray photograph of DNA taken by Rosalind Franklin in 1951 led to the understanding that DNA is composed of two long chains twisted into a helix.

### Skill Practice

### Writing a Hypothesis

In Activity A5, you will be asked to write a **hypothesis**. A hypothesis is a sentence intended as a possible explanation for observations. It is a proposed answer to a question.

Questions in science are usually cause-and-effect questions, such as “How does temperature affect the growth of rose plants?” Notice that the cause, temperature, is the manipulated variable. The effect, plant growth, is the responding variable.

A hypothesis is often written as an “if ... then...” statement. For example, *if* the temperature is increased, *then* the plants will not grow as tall. A hypothesis does not have to be the right answer—it’s just a possible answer. Scientists test the hypothesis by carrying out an investigation.

Create a cause-and-effect question and a hypothesis for each of the following statements:

1. Plants require light for photosynthesis.
2. Copper loses its brittleness if it is heated before being hammered into tools.
3. Fermentation keeps food from rotting.
4. Hydrocarbon combustion produces carbon dioxide and water.
5. Sodium and chlorine react to produce sodium chloride (table salt).

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Ionic or Molecular?

## The Question

How can substances be classified as ionic or molecular based on their properties?

## The Hypothesis

Write a hypothesis that answers the question above.

## Variables

Identify the manipulated and responding variables.



## Materials and Equipment

sodium chloride

sugar

potassium iodide



bees wax

Epsom salts

naphthalene flakes



2 hot plates

6 test tubes

aluminium foil

conductivity meter

**CAUTION:** Naphthalene gives off toxic fumes when heated. Use the fume hood when heating it. Beware of hot surfaces to avoid burns.

## Procedure

- 1 Copy the data table below into your notebook.
- 2 Plug in a hot plate and set it to medium heat. This hot plate will be used in step 9. Place another hot plate in the fume hood and plug it in. It will be used in step 10.
- 3 Obtain a small sample of about 1 g of each substance (an amount the size of a fingernail). Place the samples of the first five substances from the materials list on one piece of aluminium foil. Do not mix them. Place the naphthalene flakes on a separate piece of aluminium foil.
- 4 Note the appearance of each substance. In particular, do they appear crystalline or waxy?
- 5 Using a spatula, try to crush a small piece of each substance. Record your observations.
- 6 Carefully determine whether any of the samples have a characteristic odour. (See Student Reference 1: Safety for information on how to detect odours safely.) Record your observations.
- 7 Place a few crystals of one substance in a test tube. Add water and note whether any dissolve. The fewer the crystals placed in the test tube, the easier it is to observe if any dissolve. Repeat this step for each substance. Use a clean test tube each time. The same test tube can be used each time, as long as it is washed out between uses.

Substance	Appearance	Hardness	Odour	Solubility in Water	Conductivity	Melting Point
sodium chloride						
sugar						
potassium iodide						
bees wax						
Epsom salts						
naphthalene flakes						

- 8 (Your teacher may demonstrate this step). Test each sample that appeared to dissolve to see whether it conducts electricity.
- 9 Place the aluminium foil containing the five samples on the hot plate. Note the order in which the samples melt. Some may not melt at all. Record your observations.
- 10 Place the aluminium foil holding the naphthalene flakes on the hot plate in the fume hood. Note how long they take to melt.
- 11 Follow your teacher's instructions for disposing of all the substances you have used.
2. Write "bees wax" in one circle and "Epsom salts" in the other.
3. Write the names of other substances that are similar in their properties to bees wax in the same circle where you wrote "bees wax."
4. Write the names of other substances that are similar in their properties to Epsom salts in the same circle where you wrote "Epsom salts."
5. If any substances do not clearly fit into either group, write their names in the overlapped area.
6. Decide which group of compounds are molecular and which are ionic.

### Analyzing and Interpreting

1. Draw two circles that overlap each other to form a Venn diagram. Make them large enough to write the names of the six test substances inside.

### Forming Conclusions

7. Identify each compound tested as ionic or molecular. Describe how you used their properties to classify them.

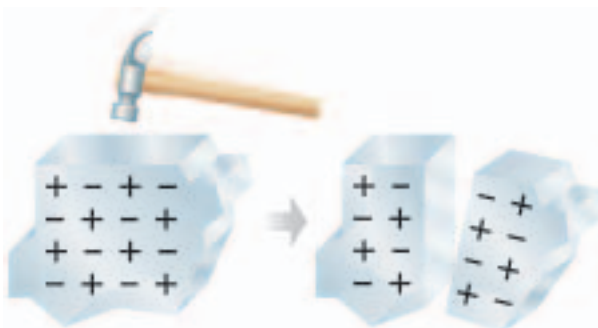
## Identifying Ionic Compounds

Recall that ionic compounds always contain positive and negative ions. One is a cation, which is a positive metal ion, such as  $\text{Fe}^{3+}$ , or the positive ammonium ion  $\text{NH}_4^+$ . The second ion is always an anion, which is a negative non-metal ion, such as fluoride,  $\text{F}^-$ , or a negative polyatomic ion, such as the phosphate ion  $\text{PO}_4^{3-}$ .

You can recognize an ionic compound by inspecting its formula, and noting the presence of a cation. In other words, if the formula of a compound begins with a metal ion or with the  $\text{NH}_4^+$  ion, the compound is ionic. Table A2.13 shows examples of some ionic compounds.

**TABLE A2.13** Examples of Ionic Compounds and Their Properties

Property	$\text{NaCl}_{(s)}$	$\text{MgSO}_{4(s)}$	$\text{PbI}_{2(s)}$	$\text{NH}_4\text{NO}_{3(s)}$
colour	white	white	bright yellow	white
state at room temperature (25°C)	solid	solid	solid	solid
melting point/freezing point	801°C	1124°C (decomposes)	400°C	170°C
malleable	no	no	no	no
soluble in water	yes	yes	slightly	yes
conductor as solid	no	no	no	no
conductor in solution	yes; strong	yes; strong	yes; weak	yes; strong



**FIGURE A2.23** (a) Before being hit, all ions alternate precisely.

(b) After being hit, the positive ions momentarily move close to positive ions, and negative ions move close to negative ions, causing the crystal to split.

## Properties of Ionic Compounds

Ionic compounds share many of the following properties. These properties help to distinguish ionic compounds from molecular compounds.

### *High Melting Point*

Notice that the compounds listed in Table A2.13 all have high melting points. Because of their high melting points, all ionic compounds are solids at room temperature. The attractions between the cations and the anions in a solid ionic compound are so strong that the ions are held in the tight, highly organized crystal lattice. In the lattice, all the negative ions are surrounded by positive ions, and the positive ions are surrounded by negative ions (Figure A2.23(a)). A large amount of energy must be added in the form of heat before the ions can begin to move past each other in the liquid state.

### *Retention of Crystal Shape*

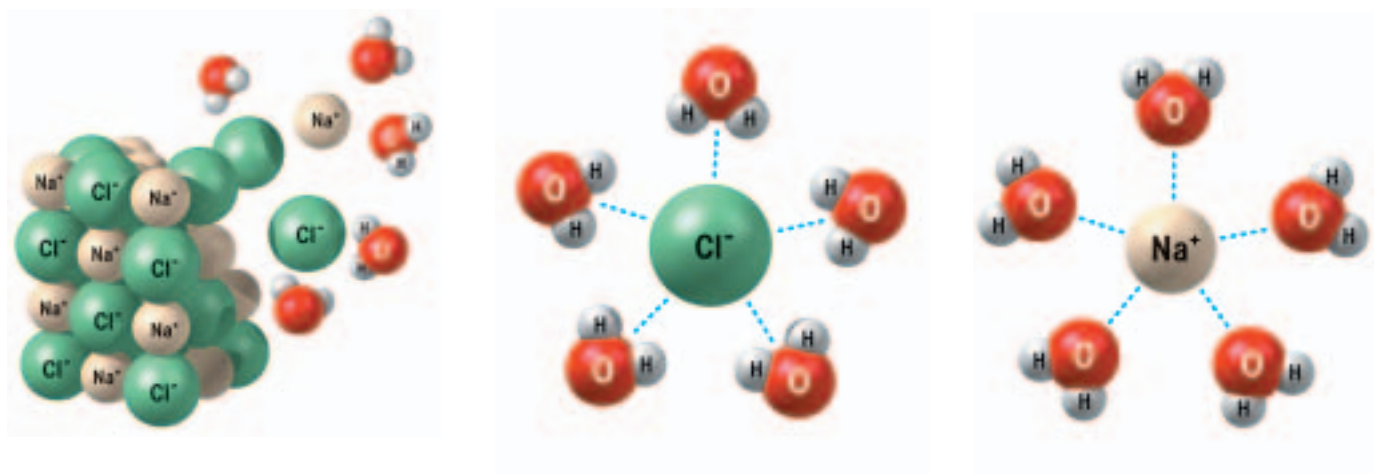
If you examine grains of table salt closely, you can see that each crystal is made up of perfectly flat surfaces. If you grind the salt into a fine powder, and then examine the powder with a microscope, you will see that all the pieces are still little crystals. Each piece still has flat surfaces, just very much smaller. This results from the alternating positive and negative alignments of the ions in the crystal. When the crystal is hit, positive ions line up with each other, and negative ions line up with each other (Figure A2.23(b)). The two parts of the crystal fly apart, producing new perfectly flat surfaces. Ionic compounds retain their crystal shape. Figure A2.24 shows a crystal of table salt ( $\text{NaCl}_{(s)}$ ).



**FIGURE A2.24** Salt ( $\text{NaCl}$ ) is an ionic compound. Ionic compounds form beautiful crystals when allowed to grow under the right conditions.

### *Solubility in Water*

All ionic compounds dissolve in water to some extent because both cations and anions are strongly attracted to water molecules. This occurs because each water molecule is **polar**. One end has a slightly positive electric charge, and the other end has a slightly negative charge. You will learn more about the polarity of water later in this section. When an ionic crystal is placed in water, some ions on the surface of the undissolved crystal are attracted into the water. There they become surrounded by many water molecules (Figure A2.25). You will learn more about the solubility of ionic compounds later in this section.



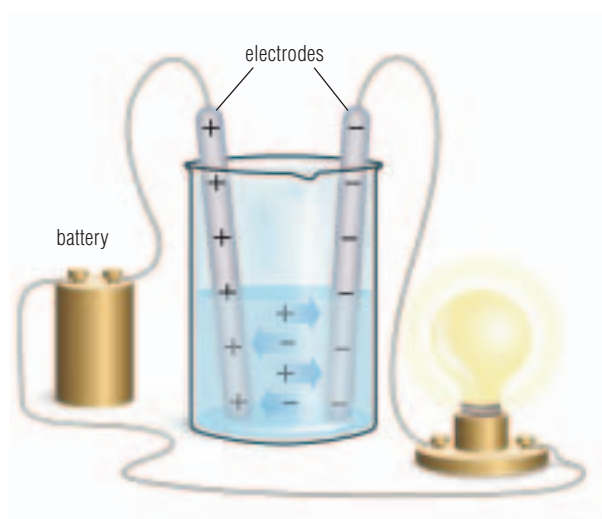
**FIGURE A2.25** Ions break off the crystal as they dissolve. Water molecules orient themselves around the cations and anions.

### Conductivity in Solution

Solutions containing ionic compounds are good conductors of electricity, unlike pure water, which has almost no conductivity. The greater the concentration of ions in solution, the more conductive the solution is. For example, a 1-L solution of 2 g of  $\text{NaCl}_{(aq)}$  in water is twice as conductive as the same volume containing 1 g of  $\text{NaCl}_{(aq)}$ . The solution with 2 g of  $\text{NaCl}_{(aq)}$  has twice as many  $\text{Na}^+_{(aq)}$  and  $\text{Cl}^-_{(aq)}$  ions as the one with 1 g of  $\text{NaCl}_{(aq)}$ . Figure A2.26 shows that ions in solution can complete a circuit for electric current to light a light bulb.

Solutions of ionic compounds are considered to be excellent **electrolytes**. An electrolyte is any solution that can conduct electricity. If a solution does not contain ions, it will not conduct. For example, a solution of table sugar,  $\text{C}_{12}\text{H}_{22}\text{O}_{11(s)}$ , contains no charged particles, just neutral molecules of  $\text{C}_{12}\text{H}_{22}\text{O}_{11(aq)}$ , so it does not conduct electricity. A solution of table sugar is not an electrolyte.

Some molecular compounds, such as  $\text{HCl}_{(g)}$ , become ionic in solution. Hydrogen chloride reacts with water to produce new ions. This is a general characteristic of acids, which will be examined in the next section.



**FIGURE A2.26** An electric current is carried by moving electrons in a wire and by moving ions in a solution.

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Constructing a Small Solubility Table

## Before You Start...

This activity involves mixing solutions to see whether a precipitate forms. Recall that a precipitate is a solid that forms when some solutions mix. This process is called precipitation.

## The Question

What combinations of ions produce a precipitate when their solutions are mixed?

## Materials and Equipment

spot plate

5 drops of each of the following solutions:

silver nitrate



strontium nitrate



sodium iodide



sodium sulfate

barium iodide

**CAUTION:** Some solutions you are using are poisonous or corrosive. Wash your hands thoroughly after handling these chemicals.

## Procedure

- 1 Copy the following table into your notebook.

	silver nitrate	strontium nitrate	sodium iodide	sodium sulfate	barium iodide
silver nitrate					
strontium nitrate					
sodium iodide					
sodium sulfate					
barium iodide					

- 2 Use the table in step 1 as a guide to where to place each solution in your spot plate. For example, place a few drops of silver nitrate in each of the five wells on the left side of the spot plate. In the top well, add a few more drops of the same solution. In the one below it, add a few drops of strontium nitrate to the silver nitrate, and so on down the column. In the next column of wells, to the right, strontium nitrate should be in all the wells, and other substances added to it.
- 3 Wait at least two minutes after mixing the solutions before making your final observations.
- 4 In your table, record whether a precipitate has formed in each well. Where a precipitate has formed, note its colour and appearance.
- 5 Do not rinse the spot plate in the sink. Some of these chemicals contain metals. They require special disposal procedures. Follow your teacher's instructions for disposing of all the substances you have used.

## Analyzing and Interpreting

1. When you mixed a solution with itself, did a precipitate form in any of the solutions?
2. Did the order in which you added solutions to each other make any difference as to whether a precipitate did or did not form? (For example, did it make a difference if you added sodium iodide to sodium sulfate, or if you added sodium sulfate to sodium iodide?) What evidence is there to support this conclusion?

- When silver nitrate and sodium iodide were mixed, a white precipitate formed. Its identity is either silver iodide or sodium nitrate. Use the results from your experiment to help you decide which of these two substances formed the precipitate.
- Identify two other substances that formed precipitates in this experiment.

## Forming Conclusions

- List three compounds that form precipitates when their ions are mixed together in a solution. Use the solubility table you constructed as you did the activity to support your conclusion.

## Solubility of Ionic Compounds

Some ionic compounds dissolve better than others. A substance that dissolves well is considered very soluble. Recall that its chemical formula would be followed by the subscript “(aq)” when it’s in solution. A substance that does not dissolve well is considered slightly soluble. Its chemical formula is followed by the subscript “(s).” Table A2.14 shows the solubility of some common ionic compounds in water. It summarizes the results of many solubility experiments.

**TABLE A2.14** Solubility of Some Common Ionic Compounds in Water

Note: Group 1 =  $\text{Li}^+$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Rb}^+$ ,  $\text{Cs}^+$ ,  $\text{Fr}^+$

Group 2 =  $\text{Be}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Sr}^{2+}$ ,  $\text{Ba}^{2+}$ ,  $\text{Ra}^{2+}$

“all” means “all compounds containing these ions”

“most” means “most compounds containing these ions”

“only with” means “only compounds containing” the ion or ions listed

Ion	Group 1 $\text{NH}_4^+$ $\text{H}_3\text{O}^+$ ( $\text{H}^+$ )	$\text{ClO}_3^-$ $\text{NO}_3^-$ $\text{ClO}_4^-$	$\text{CH}_3\text{COO}^-$	$\text{Cl}^-$ $\text{Br}^-$ $\text{I}^-$	$\text{SO}_4^{2-}$	$\text{S}^{2-}$	$\text{OH}^-$	$\text{PO}_4^{3-}$ $\text{SO}_3^{2-}$ $\text{CO}_3^{2-}$
<b>Very Soluble</b>	all	all	most	most	most	only with: Group 1 Group 2 $\text{NH}_4^+$	only with: Group 1 $\text{NH}_4^+$ $\text{Sr}^{2+}$ $\text{Ba}^{2+}$ $\text{Ti}^+$	only with: Group 1 $\text{NH}_4^+$
<b>Slightly Soluble</b>	none	none	only with: $\text{Ag}^+$ $\text{Hg}^+$	only with: $\text{Ag}^+$ $\text{Pb}^{2+}$ $\text{Hg}^+$ $\text{Cu}^+$ $\text{Ti}^+$	only with: $\text{Ca}^{2+}$ $\text{Sr}^{2+}$ $\text{Ba}^{2+}$ $\text{Ra}^{2+}$ $\text{Pb}^{2+}$ $\text{Ag}^+$	most	most	most

Recall that group 1 elements are the alkali metals, which include the very common metal ions lithium, sodium, and potassium. Table A2.14 shows that any compounds containing these ions are very soluble. Salts containing these ions are common in the ocean. As noted above, the chemical formulas for soluble compounds in solution have the subscript *(aq)*. It stands for “aqueous,” meaning that the compound is dissolved in water. For example, sodium chloride in solution is written  $\text{NaCl}_{(aq)}$ . Sodium chloride in your salt shaker is written  $\text{NaCl}_{(s)}$ .

Most compounds that contain chloride ions are also soluble, with a few exceptions. Silver chloride, for example, is only slightly soluble. Most phosphates and carbonates are only slightly soluble. This is fortunate, because these compounds are present in everything from egg shells to clam shells to bones and teeth.

Sometimes, when ionic solutions are mixed, they form a **precipitate**. A precipitate is a solid with low solubility that forms from a solution. Precipitates may form when solutions of two different ionic compounds are mixed. **Precipitation** is the process involved in forming a precipitate. You will learn more about chemical reactions that produce precipitates in section A3.3.

## Minds On ... Using the Solubility Chart

Use the solubility chart in Table A2.14 to help you answer the following questions.

- Suppose the following compounds were added to water. Indicate the solubility of each one by using the subscript *(aq)* for those that are very soluble and *(s)* for those that are slightly soluble.

- |                              |                               |
|------------------------------|-------------------------------|
| a) $(\text{NH}_4)_2\text{S}$ | f) $\text{Au}(\text{NO}_3)_3$ |
| b) $\text{AgCl}$             | g) $\text{PbI}_4$             |
| c) $\text{PbSO}_4$           | h) $\text{Na}_3\text{PO}_4$   |
| d) $\text{Sr}(\text{OH})_2$  | i) $\text{CuS}$               |
| e) $\text{Fe}(\text{OH})_3$  | j) $\text{AgCH}_3\text{COO}$  |

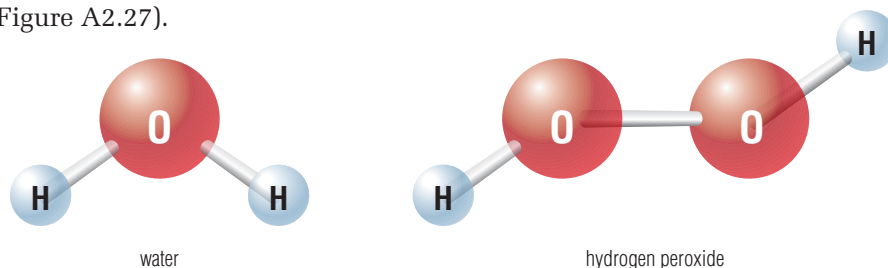
- Suppose the following compounds were added to water. Indicate the solubility of each one by stating whether it is very soluble or slightly soluble.

- potassium carbonate
- iron(II) nitrate
- copper(I) chloride
- barium hydroxide
- ammonium sulfite
- calcium sulfide
- lead(IV) bromide

## Properties of Molecular Compounds

Recall from section A2.2 that molecular compounds are made up of molecules. Molecules are groups of non-metallic atoms held together by **covalent bonds**. These very strong bonds form when non-metallic atoms share electrons. Each molecule of a compound always has the same number and proportion of atoms in it. For example, every water molecule has two atoms of hydrogen and one atom of oxygen, and its formula is written as  $\text{H}_2\text{O}_{(l)}$  (Figure A2.27).

**FIGURE A2.27** Both water and hydrogen peroxide contain hydrogen and oxygen, but in different proportions.



The attraction between individual atoms in a molecule is very strong, but the attraction between neighbouring molecules is weak. For this reason, the melting points of molecular compounds tend to be much lower than the melting points of ionic compounds. In molecular compounds, only a small amount of energy is required for the molecules to begin sliding past one another. Note that the molecule itself does not break up during melting. For this reason, melting is not considered a chemical change. The properties of five common molecular compounds are shown in Table A2.15.

**TABLE A2.15** Properties of Five Common Molecular Compounds

Property	$\text{H}_2\text{O}_{(l)}$ (water)	$\text{CH}_{4(g)}$ (methane)	$\text{C}_{18}\text{H}_{38(s)}$ (wax)	$\text{C}_8\text{H}_{10}\text{N}_4\text{O}_{2(s)}$ (caffeine)	$\text{C}_6\text{H}_{12}\text{O}_{6(s)}$ (glucose)
colour	colourless	colourless	colourless	white	white
state at room temperature (25°C)	liquid	gas	solid	solid	solid
melting point/ freezing point	0°C	−183°C	64°C	238°C	150°C
malleable	—	—	no	no	no
soluble in water	—	no	no	slightly	yes
conductor as solid	no	no	no	no	no
conductor in solution	—	—	—	no	no

Molecular substances can form beautiful crystals, such as snowflakes. Snowflakes are simply crystalline water. Unlike crystals of ionic compounds, crystals of molecular compounds crumble easily. The relatively weak attractions between molecules mean that the crystals do not hold their shape. Another difference between ionic and molecular compounds is electrical conductivity. All molecules are electrically neutral, both as solids and in solution, so they do not conduct electricity in either state.



**FIGURE A2.28** Molecular substances such as glucose can form crystals. But their crystals break down more easily than those of ionic compounds.

### infoBIT

Methane ( $\text{CH}_{4(g)}$ ) is produced by the breakdown of organic materials. Because it is produced in swamps by rotting vegetation, it is known as “swamp gas.” It is highly flammable, so some communities recover it from landfill sites for energy production. The fossil fuel natural gas is also methane.

## Special Properties of Water

One of water's most important properties is that it is polar: each water molecule has a negative end and a positive end. Water has this interesting property because of its bent shape and because of the unequal sharing of electrons in the bonds holding the hydrogen and oxygen together (Figure A2.29). This makes the oxygen end of water slightly negative, and the hydrogen end slightly positive. It also means that water molecules attract each other, just as two bar magnets attract each other if they are lined up with opposite poles together. This attraction makes it easier for water to form a liquid than if it were not polar.

Other properties would also change if water were not polar. Table A2.16 compares water with similar compounds that are not polar. From this comparison, we can see that it's likely water would boil at a much lower temperature if it was not polar, at about  $-80^{\circ}\text{C}$ .

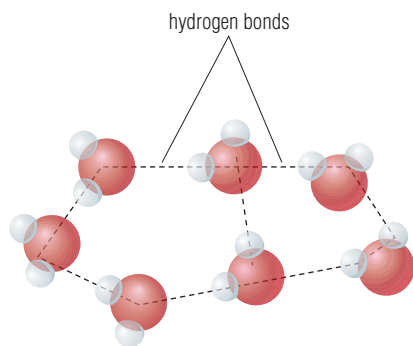
**TABLE A2.16** Boiling Points of Some Compounds Similar to Water

Compound	Boiling Point
hydrogen selenide, $\text{H}_2\text{Se}_{(g)}$	$-40^{\circ}\text{C}$
hydrogen sulfide, $\text{H}_2\text{S}_{(g)}$	$-60^{\circ}\text{C}$
water, $\text{H}_2\text{O}_{(l)}$	$100^{\circ}\text{C}$

It is hard to overstate the importance of the polarity of water. If water was not polar, all the oceans would boil away even during the coldest winter. Life on Earth would be non-existent or completely different from what we see today. Much of the thermal energy at Earth's surface is held by water in oceans, lakes, and rivers. In summer, the oceans act as a heat sink, absorbing heat from the Sun and the air. In winter, they are a heat source, radiating stored heat. Both of these effects keep Earth's surface temperatures from swinging too high or too low. Living systems depend on this stability.

### Formation of Ice

As liquid water turns to ice, the molecules spread out. They line up in a three-dimensional array that contains six-sided rings, as shown in Figure A2.30. This is the reason that every snowflake has six sides or six points. The ordering of water molecules in ice also means that there are fewer molecules in a litre of ice than in a litre of liquid water, so that liquid water is denser than ice. Because of this, ice floats. Would it matter if ice didn't float? In the winter, ice forms at the top surface of a lake because that is where it is coldest. If ice were denser than liquid water, then as a lake froze over, the ice would sink to the bottom and collect there. Eventually, the lake would freeze solid, and all the fish would die. Fish can survive through the winter because ice floats.




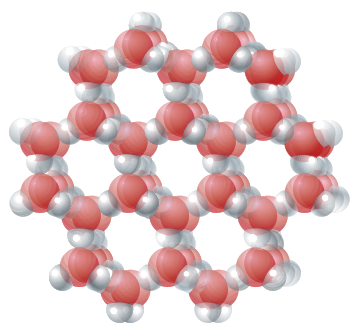
**FIGURE A2.29** Liquid water molecules are held together through the attractions caused by each molecule being slightly polar.

### reSEARCH

The weak interactions between water molecules are called hydrogen bonds. Investigate hydrogen bonding in other substances such as DNA and the plastic used in sandwich wrap.

Begin your search at

 [www.pearsoned.ca/school/science10](http://www.pearsoned.ca/school/science10)



**FIGURE A2.30** Water molecules in ice. The origin of the six-sided snowflake can be seen by the honeycomb shape that water molecules form.

## A2.3 Check and Reflect

### Knowledge

1. Explain how to recognize an ionic compound from its chemical formula.
2. Describe four properties of an ionic compound.
3. Explain how to recognize a molecular compound by its chemical formula.
4. Describe four properties of molecular compounds.
5. Water is a polar molecule. What does this mean?
6. Indicate whether each of the following compounds is slightly soluble (*s*) or very soluble (*aq*). Refer to Table A2.14 on page 57 or Table C in Student Reference 12.
  - a) NaCl
  - b)  $\text{PbCl}_2$
  - c)  $\text{PbCl}_4$
  - d)  $\text{BaSO}_4$
  - e)  $\text{Cr}_2\text{S}_3$
  - f)  $\text{CsCH}_3\text{COO}$
  - g)  $\text{K}_2\text{CO}_3$
8. For each substance below, identify it as ionic or molecular. Explain how you came to your conclusion.
  - a) Compound 1: melting point:  $48^\circ\text{C}$ , low solubility in water, flammable, mild odour, colourless solid easily crushed
  - b) Compound 2: melting point:  $800^\circ\text{C}$ , highly soluble, solution is highly conductive, hard, white crystals
  - c) Compound 3: melting point:  $185^\circ\text{C}$ , decomposes at  $190^\circ\text{C}$ , highly soluble, solution is not conductive, hard, white crystals
  - d) Compound 4: sublimes (goes from solid to gas) at  $-56^\circ\text{C}$ , moderately soluble in water, colourless, odourless
  - e) Compound 5: highly flammable liquid at room temperature, does not mix with water, less dense than water
  - f) Compound 6: colourless, odourless liquid, tends to dissolve ionic substances, boils at  $100^\circ\text{C}$
9. All of the compounds in question 8 are common materials. Suggest the identity of each material from the descriptions of the physical properties.

### Applications

7. Explain how a large body of water can moderate the temperatures of the land around it in both winter and summer.

### Extension

10. Some well water is considered “hard” because it contains high concentrations of  $\text{Mg}^{2+}$  and  $\text{Ca}^{2+}$  ions. Explain how adding a small amount of sodium carbonate to the well water can make the water “soft” by removing these ions.

## infoBIT

Another name for vitamin C is ascorbic acid. It is an essential part of our diet and is responsible for healthy muscles, skin, and gums. Many bioactive materials are acids and bases.

## A 2.4 Acids and Bases

You are already familiar with acids and bases from everyday use and from earlier science studies. Recall that an **acid** is a compound that dissolves in water to form a solution with a pH lower than 7. The vinegar in Figure A2.31 is acidic. A **base** is a compound that dissolves in water to form a solution with a pH greater than 7. The **pH** measurement indicates how acidic or basic a substance is. Recall that pH is a measure of the number of hydrogen ions in a solution.

### Acids and Bases in Your Body

Acids and bases are in the foods we eat and the products we use. They are also essential components of your own biochemistry. For example, your saliva is slightly basic so your teeth won't dissolve in acids, such as the citric acid in fruit juices. It also protects you from the acids that the bacteria in your mouth produce as a byproduct of their metabolism.

Your stomach makes hydrochloric acid strong enough to burn, as anyone who has accidentally burped up some stomach acid can confirm. What does this acid do? Some of it dissolves food, but it also has a much more important function. It acts like a chemical switch to turn on an enzyme called pepsin. Pepsin, like all enzymes, speeds up chemical reactions in living systems. The reaction that pepsin speeds up is the digestion of protein into amino acids, which are the building blocks of proteins. Pepsin would be lethal if it passed into the intestine without being deactivated. It would begin to digest the digestive tract itself.

An organ called the pancreas produces sodium hydrogen-carbonate (the same chemical as in baking soda) and other bases that neutralize the stomach acid. This deactivates the pepsin. After that, the sodium hydrogencarbonate goes into the bloodstream, making it very slightly basic. Sodium hydrogencarbonate has the amazing property that it can neutralize both acids and bases that enter the blood. When acids and bases are neutralized, they lose their characteristic properties. You will learn more about neutralization later in this section.

Sodium hydrogencarbonate is an example of a **buffer**. It is a substance that can keep the pH of a solution nearly constant despite the addition of a small amount of acid or base.

Acids and bases are all around us and inside us. How can we make sense of this amazing variety of chemicals? We can begin by classifying them as acidic, basic, or neutral according to their chemical and physical properties.



**FIGURE A2.31** The pH of vinegar is less than 7, indicating that vinegar is acidic.

## Properties of Acids and Bases

You are already an expert at sorting out acids and bases. You were born with this skill—it is hard wired into your sense of taste. The four basic tastes are sweet, sour, salty, and bitter. If you have ever had soap in your mouth, you know the taste of a base—bitter. You know the taste of acid from lemons (citric acid) and vinegar (acetic acid). You probably would not be surprised to find that *acidus* is the Latin word for “sour.” Given the commonness of these chemicals, it is no wonder that your tongue is able to detect them.

Acidic and basic solutions even feel different. Bleach, soap, and ammonia cleanser all feel slippery, and all are bases. Bleach, of course, must be washed off quickly because it is corrosive to skin. Acid solutions do not feel slippery.

Remember that taste and touch tests are fine for food in the kitchen, but they should never be performed in the lab. Other tests are needed to classify acids and bases. For example, adding a metal to a solution could help determine if the solution is acidic or basic. Acids react with metals, although some acids, such as nitric acid, react more vigorously with metals than other acids. And some metals, such as copper and gold, are better than other metals at resisting attack by acids. Most bases do not attack metals. Neither does pure water, which is a neutral substance. This ability to react with metals could be used to distinguish acids from bases and neutral substances. But there is an easier way—by determining the pH.

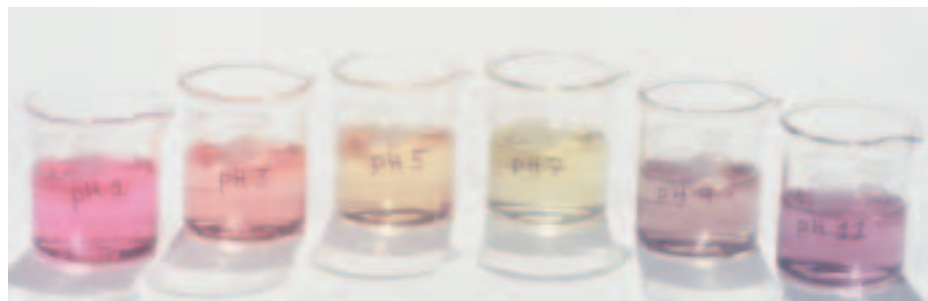
## Indicators

Acid–base indicators are chemicals that are used to determine if a solution is an acid or a base. Indicators change colour depending on the pH of a solution. Litmus indicator is a chemical derived from lichen, a plant-like organism. Litmus is usually dried onto paper to make it easier to use in tests. In acid, blue litmus paper turns red, and in base, red litmus paper turns blue. In a neutral solution, such as pure water, litmus paper does not change colour. Red litmus paper stays red, and blue litmus paper stays blue. Litmus is a very common indicator, so it’s useful to memorize the colour changes (Figure A2.32).

There are many indicators, and each changes colour at a specific level of acidity. A **universal indicator** is a mixture of several indicators that change colour as the acidity changes (Figure A2.33).

ACID  
RED  
BASE  
BLUE

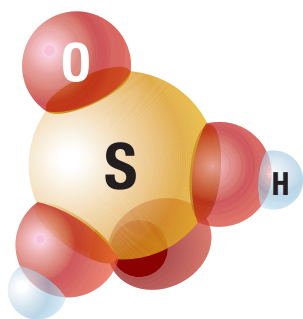
**FIGURE A2.32** This diagram shows a memory trick for remembering the colour of litmus in acid and in base.



**FIGURE A2.33** The colour of a universal indicator changes at a variety of pH values.

## infoBIT

Understanding the pH scale can help you understand the seriousness of the problem with acid rain. Ordinary rainwater is about pH 6. Acid rainwater can have a pH as low as 3. A difference of 3 units on the pH scale means that acid rain can be as much as 1000 times more acidic than ordinary rain.



**FIGURE A2.34** Sulfuric acid molecule

## The pH Scale

Recall that the pH scale is a measure of acidity. Most solutions are between 0 and 14 on the pH scale. A **neutral** substance has a pH of 7 (at 25°C). It is neither acidic nor basic. Acidic substances have pH values below 7. The closer the pH is to 0, the more acidic the substance is. Stomach acid is about pH 1.5. Vinegar is less acidic at about pH 3. Normal rainwater is slightly acidic and has a pH of about 6. Bases have pH values greater than 7. Blood is slightly basic, with a pH of 7.4. Soaps have pH values between 8 and 10.

Every increase of 1 on the pH scale indicates an increase of 10 in how basic a substance is. A solution with a pH of 9 is 10 times more basic than one with a pH of 8. Similarly, a decrease of 1 on the pH scale indicates a 10-times increase in acidity.

Acidic and basic solutions can be classified according to the properties shown in Table A2.17.

**TABLE A2.17** Properties of Acids and Bases

Property	Acid	Base
taste	sour	bitter
touch	not slippery	slippery
reaction with metals (e.g., magnesium)	metal corrodes H <sub>2</sub> bubbles form	no reaction
litmus indicator	red	blue
electrical conductivity	conductive	conductive
pH of solution	< 7	> 7

## Naming Acids

The formula for a compound can help you determine if it is an acid or a base. H, the symbol for hydrogen, tends to appear one or more times on the left side of the formula of an acid. For example, in hydrochloric acid, HCl<sub>(aq)</sub>, the hydrogen symbol appears on the left. In acetic acid, which is the acid in vinegar, hydrogen appears on the right in a group of symbols known as an organic acid group: -COOH. To identify acids from their formulas, look for H on the left side of the formula or COOH on the right. Some common acids are listed in Table A2.18.

Notice that the acids listed in Table A2.18 are all aqueous. The IUPAC recommends naming acids as aqueous substances containing the IUPAC name of the compound. For example, HCl<sub>(aq)</sub> is called aqueous hydrogen chloride; and H<sub>2</sub>SO<sub>4(aq)</sub> is called aqueous hydrogen sulfate.

However, acids have been known for thousands of years, and they are very common compounds. Because of this, other naming systems exist that are still popular. For example, the names of acids that contain hydrogen and one other non-metallic element can be written with the prefix “hydro-” and the suffix “-ic.” In this system, HCl<sub>(aq)</sub> is called hydrochloric acid. Following this pattern, HF<sub>(aq)</sub> is called hydrofluoric acid.

Acids that contain oxygen, such as  $\text{H}_2\text{SO}_{4(aq)}$ , follow a different system that is based on the name of the anion. In this naming system, if the anion ends in “-ate,” the name of the acid that is derived from it ends in “-ic.” For example,  $\text{H}_2\text{SO}_{4(aq)}$  contains the sulfate anion ( $\text{SO}_4^{2-}$ ), an anion whose name ends in the suffix “-ate.” In this case, the acid’s name begins with “sulfur” (the first element in the anion) and ends with “-ic.” It is called sulfuric acid. Another example is  $\text{H}_3\text{PO}_{4(aq)}$ . Its IUPAC name is aqueous hydrogen phosphate, but it is also called phosphoric acid. Similarly,  $\text{HNO}_{3(aq)}$  is called both aqueous hydrogen nitrate and nitric acid. If the anion’s name does not end in “-ate,” other naming systems are used. You will learn about these naming systems in later courses.

**TABLE A2.18** Formulas, Names, and Uses of Some Common Acids

Acid	Name	Common Name	Use
$\text{HCl}_{(aq)}$	hydrochloric acid or aqueous hydrogen chloride	muriatic acid	concrete cleaning
$\text{H}_2\text{SO}_{4(aq)}$	sulfuric acid or aqueous hydrogen sulfate	battery acid	car batteries, fertilizer manufacturing
$\text{HNO}_{3(aq)}$	nitric acid or aqueous hydrogen nitrate	—	fertilizer manufacturing, metal refining
$\text{H}_3\text{PO}_{4(aq)}$	phosphoric acid or aqueous hydrogen phosphate	—	sour taste in soft drinks, fertilizer manufacturing
$\text{HCOOH}_{(aq)}$	methanoic acid	formic acid	wool dyeing, leather tanning
$\text{CH}_3\text{COOH}_{(aq)}$	ethanoic acid	acetic acid	vinegar

## Skill Practice

## Controlling Variables

In Activity A7, you will qualitatively compare the concentration of vitamin C in several different beverages. To do this, you will have to control a certain variable so you can observe its effects. In previous science studies, you learned that the **manipulated variable** is the condition that is deliberately changed by the experimenter. The **responding variable** is the condition that changes in response to the manipulated variable. The responding variable must be something that can be measured. To test the effect of a manipulated variable, it is important that only that one variable is being changed. All other variables in an experiment must be controlled. In other words, they must be kept exactly the same.

1. A student wants to determine which freezes faster, salt water or fresh water. She adds 10 g of salt to a beaker containing 100 mL of water, 20 g of salt to a beaker containing 150 mL of water, and no salt to a beaker containing 50 mL of water. All of the substances are at

room temperature at the beginning of the experiment. All will be placed in a freezer where the temperature is  $-5.0^\circ\text{C}$ .

- a) Identify the manipulated variable.
  - b) Are the other variables being controlled? If they are not, describe how the conditions can be controlled so that only the manipulated variable is changed.
2. You are asked to determine the effect of turbulence on the amount of dissolved oxygen in water. Turbulence is the violent disturbance of a fluid, such as water or air. You will use an indicator that tells you the amount of dissolved oxygen present in a sample. You will use water that has had the oxygen content reduced by being boiled and cooled. You will simulate turbulence by shaking a sample of water.
    - a) What is the manipulated variable in this experiment?
    - b) What variables must be controlled?

## Design a Lab

## Required Skills

- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

## Vitamin C in Beverages

Vitamin C is ascorbic acid. In this activity, you will test a procedure to detect vitamin C in a solution. You will then design a qualitative procedure to compare the concentration of vitamin C in a number of beverages such as orange juice, soda pop, or lemonade.

## The Question

Which beverage has the highest concentration of vitamin C and which has the lowest?



## Materials and Equipment

1 multivitamin tablet	10-mL graduated cylinder
iodine/starch solution	
several samples of juices, soda pops, or other beverages	at least 6 medium test tubes
water	stirring rod
mortar and pestle	2 droppers
100-mL beaker	test tube rack

**CAUTION:** The iodine/starch solution stains. Handle carefully.

## Design and Conduct Your Investigation

## Part 1: Determining How a Starch/Iodine Solution Responds to a Vitamin C Solution

- 1 Use the mortar and pestle to grind up the multivitamin tablet. Dissolve most of the grindings in about 100 mL of water in a 100-mL beaker. Stir the mixture with a stirring rod. Some of the grindings may not dissolve. This is not a problem.
- 2 Use the graduated cylinder to measure 5 mL of iodine/starch solution into a test tube.

- 3 Use a dropper to add the vitamin C solution to the iodine/starch solution drop-by-drop. Observe the reaction.
- 4 Using a clean dropper, do a similar test by adding water to another sample of iodine/starch solution in another test tube. Observe. Note: You *must* use a clean dropper for this step to prevent contamination of your water with vitamin C.

## Part 2: Ranking the Test Beverages from Greatest to Lowest Concentration of Vitamin C

- 5 Select several beverages to be tested. It might be interesting to test some that are known to contain vitamin C, along with some with an unknown vitamin C content.
- 6 Develop a test procedure to rank the beverages from most concentrated to least concentrated in vitamin C content.
- 7 Have your teacher approve your procedure.
- 8 Test the beverages.
- 9 Follow your teacher's instructions for disposing of the liquids.
- 10 Write a summary report that describes:
  - your observations of what a positive test and a negative test for vitamin C look like
  - your written test procedure
  - the controlled, manipulated, and responding variables in your procedure
  - your test data
  - your ranking of the test beverages from most concentrated to least concentrated

## Recognizing Bases by Their Formulas

Bases are more difficult to recognize by their formulas than acids are. The presence of the hydroxide ion ( $\text{OH}^-$ ) with a metal ion or the ammonium ion usually indicates that a substance is basic. For example,  $\text{NaOH}_{(s)}$  forms a base when dissolved in water. However, substances with other kinds of formulas can also be basic. For example, when ammonia ( $\text{NH}_{3(g)}$ ) is dissolved in water, the resulting solution is basic. You will study these bases in more advanced chemistry courses. For now, consider any compound with high solubility and an OH on the right side of the formula to be a base. Some common bases are listed in Table A2.19.

**TABLE A2.19** Formulas, Names, and Uses of Some Common Bases

Base	Name	Common Name	Application
$\text{NaOH}_{(s)}$	sodium hydroxide	caustic soda	drain cleaner
$\text{KOH}_{(s)}$	potassium hydroxide	caustic potash	leather tanning
$\text{NH}_4\text{OH}_{(aq)}$	ammonium hydroxide	ammonia solution	window cleaner
$\text{Ca}(\text{OH})_{2(s)}$	calcium hydroxide	slaked lime	glass, cement, and steel manufacturing
$\text{Mg}(\text{OH})_{2(s)}$	magnesium hydroxide	milk of magnesia	laxative, antacid
$\text{Al}(\text{OH})_{3(s)}$	aluminium hydroxide	—	antacid, wastewater treatment

## Acids and Bases in the Home

We all use acids and bases in the home, often when we are not even aware of it. Lemon juice, vinegar, and some toilet bowl cleaners are acids. Most soaps and cleaners are bases, such as oven cleaner, hand soaps, and many window cleaners. Bases are excellent at dissolving and dislodging oil and grease. Household bleach is also basic, as well as being an oxidizing agent. This means it has the ability to break down stains into colourless compounds. Drinks such as coffee, tea, and soda pop are acidic. Shampoos that are “pH balanced” are often slightly acidic, to make them more gentle on hair than standard soaps, which, being basic, tend to strip out oils. Advertisers came up with the term “pH balanced” so they would not have to try to explain how an acidic product could be good for your hair!

Many efforts have been made to minimize the use of toxic or highly corrosive chemicals in the household. At one time, arsenic and mercury products were commonplace in the kitchen. These have been replaced by much more benign and environmentally friendly chemicals. Even so, many chemicals will react strongly if mixed together. Acids and bases generally react when mixed, and many otherwise-safe household chemicals become dangerous when mixed improperly. Always read the labels of household cleaning products.

## The pH of Common Household Materials

### Purpose

To test the pH of a variety of household chemicals



### Materials and Equipment

droppers  
spot plate  
small beaker  
universal indicator, pH test paper, or pH meter  
distilled water (if using pH meter)  
known and unknown solutions used in the kitchen, bathroom, or laundry

**CAUTION:** Acids and bases can burn. If any spill, wash immediately with cold water.

- Place a few drops of each solution into separate wells of a spot plate. Do not mix them.
- Add either a few drops of universal indicator or a 1-cm strip of pH paper to each sample. If you are using a pH meter, rinse the probe with distilled water after each test.
- Record the pH of each solution.
- Follow your teacher's directions for disposing of the solutions you have used.

### Procedure

- Make a data table with space for recording the following for each test solution:
  - its name
  - your prediction about whether it is acidic, basic, or neutral
  - its measured pH

### Questions

- Draw a vertical line about 15 cm long. Write the number 1 at the top, 7 in the middle, and 14 at the bottom.
- For each test solution, find the place along the line that matches its pH number, and record its name beside its pH.
- Decide whether each solution is acidic, basic, or neutral.

### reSEARCH

Hydrochloric acid is also known as muriatic acid and is available in hardware stores. Research three ways that it can be used around the home. Begin your search at



[www.pearsoned.ca/school/science10](http://www.pearsoned.ca/school/science10)

## Neutralization

When acids and bases react together, both acidic and basic properties disappear. This is the process of **neutralization**. Neutralization is the reaction between an acid and a base that produces water and a compound called a salt. It is a very important and common process. For example, the pain of a bee sting is caused by methanoic acid attacking nerves in the skin. The bee secretes the acid, which dissolves the nerve endings in the skin. This causes the nerves to fire continuously, sending pain signals to the brain. Cream containing ammonia can be used to limit the pain. Ammonia is a base so it neutralizes the acid and prevents further damage to the nerve endings. In industry, countless manufacturing processes produce acidic or basic waste that must be neutralized.

## A2.4 Check and Reflect

### Knowledge

1. Use the chemical or physical properties identified below to classify each solution as acidic, basic, or neutral. For example, solution (a) is basic.
  - a) feels slippery and conducts electricity
  - b) reacts with magnesium to produce bubbles and conducts electricity
  - c) red litmus stays red and blue litmus turns red
  - d) blue litmus stays blue and red litmus stays red
  - e) tastes sour and feels wet but not slippery
  - f) does not conduct electricity, and red litmus stays red
  - g) has a pH of 3 and turns litmus red
  - h) has a pH of 10 and blue litmus stays blue
  - i) conducts electricity and has a pH of 7
  - j) tastes bitter and does not react with magnesium
2. What is an acid–base indicator?
3. From the following formulas, decide whether the solution is an acid, a base, or neither.
  - a)  $\text{KOH}_{(aq)}$
  - b)  $\text{H}_2\text{SO}_{4(aq)}$
  - c)  $\text{NaCl}_{(aq)}$
  - d)  $\text{CH}_3\text{COOH}_{(aq)}$
  - e)  $\text{HCl}_{(aq)}$
  - f)  $\text{Mg}(\text{OH})_{2(aq)}$
  - g)  $\text{C}_6\text{H}_5\text{COOH}_{(aq)}$
4. State the name or the formula for each of the following substances:
  - a) aqueous hydrogen nitrate
  - b) cesium hydroxide
  - c) ethanoic acid
  - d) calcium hydroxide
  - e) aqueous hydrogen chloride
  - f) phosphoric acid
  - g)  $\text{KOH}_{(aq)}$
  - h)  $\text{HBr}_{(aq)}$
  - i)  $\text{H}_2\text{SO}_{4(aq)}$
  - j)  $\text{Mg}(\text{OH})_{2(aq)}$

### Applications

5. Draw a horizontal line to represent a pH scale. At the left end of the line write 1, in the middle write 7, and at the right end write 14. Use this scale to complete the following tasks.
  - a) Place the following three labels at the correct place on the scale: neutral, strongly acidic, strongly basic.
  - b) On the acidic end of the scale, write the following four labels in the correct relative order: acid rain, normal rain, lemon juice, stomach juices.
  - c) On the basic end of the scale, write the following four labels in the correct relative order: a concentrated solution of baking soda, human blood, oven cleaner ( $\text{NaOH}_{(aq)}$ ), window cleaner (ammonia).
6. Why is a universal indicator more useful than litmus paper for measuring pH in some applications?
7. Some hydrochloric acid is placed in a beaker, and a pH meter is set into the solution. It reads pH 1.5.
  - a) Describe how the pH will change when  $\text{NaOH}$  solution is added drop-by-drop to the acid.
  - b) Will the conductivity of the solution change during the addition of the  $\text{NaOH}_{(aq)}$ ? Why or why not?

### Extensions

8. A solution is adjusted from pH 8 to pH 4.
  - a) How many times more acidic has the solution become?
  - b) How many times less basic has the solution become?
9. Find out the structure of the organic acid group  $-\text{COOH}$ . Build a model of ethanoic acid,  $\text{CH}_3\text{COOH}$ .

Most jurisdictions regulate the disposal of computer parts and other electronic components as hazardous waste. Many landfills ban old computer parts because internal circuit boards and CPUs contain heavy metals.

## A 2.5 Our Chemical Society

All substances, natural and manufactured, are chemicals. Water, gases in the air, the components of our bodies—all are chemicals. Our society relies heavily on manufactured chemicals including paints, plastics, fertilizers, and pesticides. Many of these chemicals are potentially hazardous, but we continue to produce and use them because they have many benefits. Guidelines and regulations, such as environmental laws and WHMIS, reduce the potential for harm to human health and the environment.

Look at the materials in the room where you are sitting. Try to find something in the room that was *not* made using potentially toxic or hazardous chemicals. Paint was toxic when it was wet. Even unpainted wood would have been oiled or stained. Do you see any plastic? There may be more than you realize. Plastic fibres are present in many clothing materials, in your pen, and in carpeting and other flooring materials. Many plastics are produced from compounds that are toxic. However, the final plastic products are generally very stable, unreactive, and non-toxic.

### Issues Related to Chemicals

Issues involving the use of hazardous material go beyond whether the material itself is safe. For example, they include concerns about the health of the workers exposed to toxic substances during manufacturing. They also include concerns about poisonous substances escaping into the environment during manufacturing. Many manufacturing processes produce byproducts that must be disposed of. These problems can lead to the final product being safe, while making it is not.

Some products are safe until they are thrown away. For example, some batteries contain mercury. Mercury is a poison, but it is not a problem as long as the battery remains sealed. A battery may be used for mere hours or days, but it may spend a decade in a ditch slowly leaching mercury into groundwater. Proper disposal is essential to protect people and the environment from hazardous chemicals.

### *Environmental Effects*

Some chemicals are safe for people to handle but may cause long-term environmental damage. Chlorofluorocarbons (CFCs) are non-toxic, non-flammable chemicals used mainly in cooling systems. They contain chlorine, which acts as a catalyst in the upper atmosphere and causes the destruction of Earth's ozone layer. It is estimated that CFCs released 50 years ago are still in the upper atmosphere. CFCs are no longer manufactured in Canada or used in new air conditioners and refrigerators. When older appliances are serviced or no longer useful, the CFCs in them must be recycled or destroyed. In Unit D: Energy Flow in Global Systems, you will learn about the Montreal Protocol, an international agreement to phase out the production and use of CFCs.

These changes in the way we use CFCs have paid off. In the 10 years between 1990 and 2000, CFC emissions dropped to one-seventh of their 1990 value. But the effects of these emissions are long lasting. It is predicted that the ozone hole will not be eliminated until about the time your grandchildren are in high school.

## Health Concerns

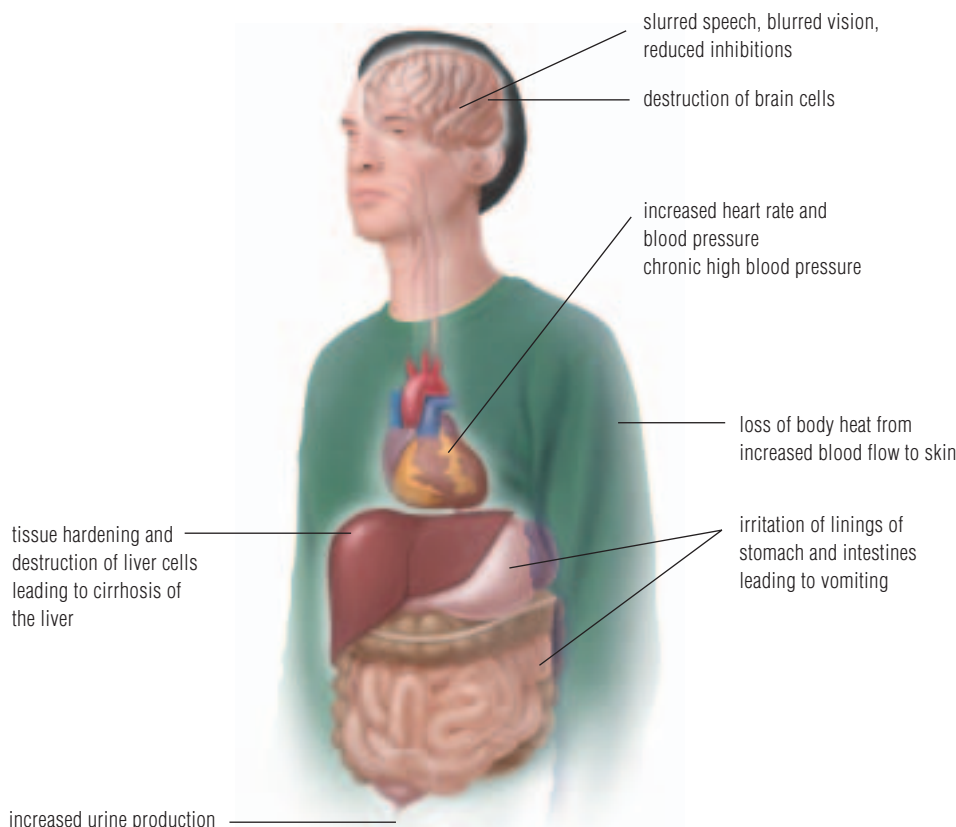
Many people use chemical substances for recreational purposes, and some of these substances can be toxic. The two most commonly used hazardous recreational chemicals are alcohol and nicotine.

### Alcohol

Alcohol is an example of a chemical that is toxic when used in large amounts. The alcohol used in beverages is ethanol. Its formula is  $\text{CH}_3\text{CH}_2\text{OH}_{(l)}$ . Alcohol is considered to be a drug because of its effects on the body. The excessive use of alcohol can lead to destruction of the liver, the kidneys, and brain cells (Figure A2.35). It can cause physical dependence, also called **addiction**. Physical dependence occurs when the body becomes used to a drug and needs it to function. Alcoholism is an addiction to alcohol.

Alcohol abuse can also lead to psychological dependence. In psychological dependence, the use of the drug is linked to certain moods or feelings. When the drug wears off, the feeling disappears. The person drinks more alcohol to try to recapture the mood or feelings. Both physical and psychological dependence prevent people from controlling their drug use, and can seriously damage their health.

A mother who consumes alcohol during pregnancy can cause permanent damage to her baby. Babies born with fetal alcohol spectrum disorder (FASD) suffer from brain damage, slow growth, heart defects, and mental disabilities. No safe level for alcohol consumption during pregnancy has been determined. Doctors advise pregnant women not to drink alcohol at all.



**FIGURE A2.35** Alcohol abuse damages health in many ways.

Alcohol misuse costs lives in other ways by leading to high-risk types of behaviour, three of which are significant killers. The first is driving while drunk. The second dangerous behaviour is binge drinking, where a large amount of alcohol is consumed quickly. The blood alcohol level becomes so high that it affects parts of the brain and nervous system that control breathing and heartbeat. The drinker then dies because breathing stops or the heart stops beating, usually while the drinker is unconscious. A common way to die from alcohol poisoning is to vomit while unconscious, and then inhale the vomit and suffocate. The third dangerous behaviour is the use of alcohol in combination with some other drug—prescription, over the counter, or illegal. This is dangerous because the mixture of drugs affects the body in ways that can cause death at relatively low levels of blood alcohol.

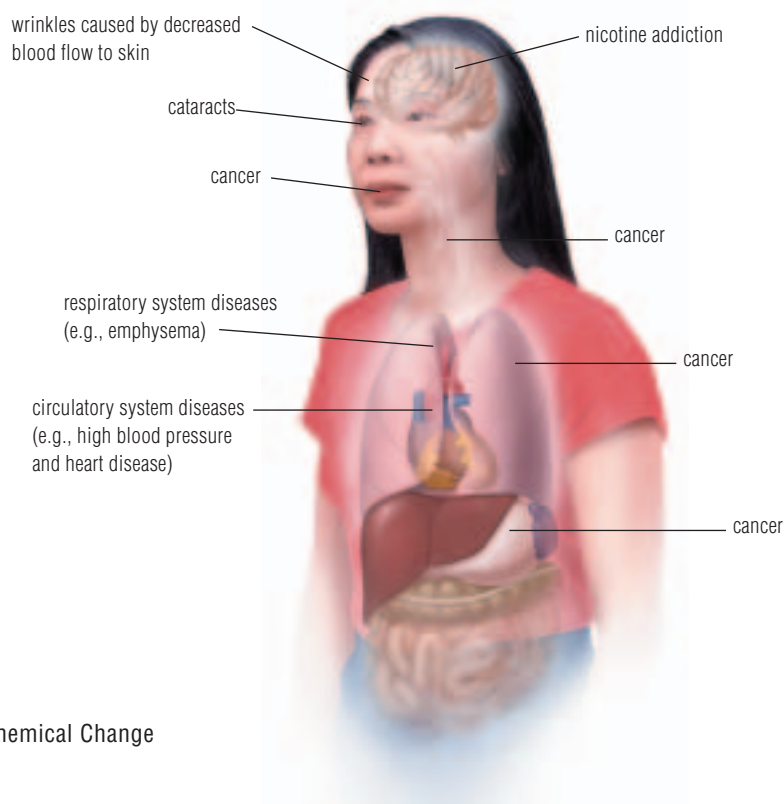
### ***Nicotine and Other Tobacco-Related Chemicals***

Nicotine, like alcohol, is a highly addictive drug. It is present in all tobacco products, including cigarettes, cigars, and chewing tobacco. People addicted to nicotine experience both psychological and physical dependence. Most people are unaware of their addiction until they try to stop smoking and cannot.

Cigarettes are the most common source of nicotine. But nicotine is only one of the chemicals that make cigarettes dangerous. Cigarette smoke is many times more harmful than the most polluted air. It contains large amounts of carbon monoxide, a poison that is also released from car exhaust. Thirty percent of cigarette smoke is composed of a mixture called tar, which is made up of over 3000 chemicals including formaldehyde and benzene, a hazardous substance. Cigarette smoking damages both the respiratory system and the circulatory system (Figure A2.37). A heavy smoker has a 20 times greater chance of developing lung cancer than a non-smoker does. About one-third of all cancer deaths in our society are caused by smoking (Figures A2.36 and A2.37).



**FIGURE A2.36** Smoking can cause mouth cancer.



**FIGURE A2.37** Cigarette smoking damages health in many ways.

Many cities in Canada have regulations controlling smoking in workplaces, including restaurants and pubs. Some require an outright ban. Others include partial bans; and others require special ventilation systems for smoking areas.

1. In groups of about four, brainstorm the opinions of different interest groups including smoking employees, non-smoking employees, smoking customers, non-smoking customers, owners, and Workers' Compensation Board representatives. (The Workers' Compensation Board is responsible for protecting workers' health and safety.)
2. Each person in your group then picks one of the interest groups and attempts to argue its point of view. You do not need to feel restricted to "expected" opinions. For example, smokers may argue for a smoking ban. Presenting good reasons for the opinion is the main objective.
3. Your teacher may bring all the groups together for a class discussion.

Cigarette smoke is dangerous to non-smokers as well as smokers. Passive smokers are those who are exposed to smoke from other people's tobacco products. Studies show that passive smokers have an increased risk of cancer. They also may experience itchy, watery eyes, and throat irritation. Many workplaces, including restaurants, are smoke-free so that workers are not exposed to secondhand smoke from other workers or customers.

## Benzene—A Regulated Substance

You have probably seen presentations made with an overhead projector. You may have used one yourself, or your teacher may have used one in science class. The sheets of clear plastic used for overheads are called acetate sheets because they are made with a type of plastic called acetate.

The process for making acetate plastics uses several compounds, one of which is benzene. Benzene is a hazardous chemical that is both toxic and flammable, but it can be used safely if proper procedures are carefully followed. Why use benzene if it can be harmful? Benzene continues to be used because it is important in many applications. It is one of the top 20 chemicals by volume produced in North America. It is used to make dyes, detergents, and medicines, such as aspirin. These substances do not have benzene's toxic properties. Environmental and health concerns are met by keeping benzene contained.

In previous science courses, you may have learned how to transport, handle, and store domestic materials, such as pesticides and motor oils, safely. At the industrial level, the safeguards are even greater because of the potential for large-scale damage. The huge volumes of potentially hazardous substances used mean that a spill or leakage from a single accidental release could have a major impact on people and the environment.

### *Safe Transportation and Handling of Benzene*

Benzene is a regulated substance. This means it must be used only according to strict guidelines that are reviewed and revised from time to time. For example, it used to be common to ship benzene by rail car in volumes of 80 m<sup>3</sup>. The potential release from a single rail car was considered too dangerous, so current regulations limit the volume to 20 m<sup>3</sup>.

The guidelines to protect workers who produce, transport, and dispose of benzene are very specific. For example, workers should not be exposed to an average benzene concentration of more than 1 part per million (ppm). At higher concentrations, workers must wear masks with activated charcoal filters. These measures may seem complicated, but they are designed to protect workers and still allow chemical processing to continue.

Good science and technology make it possible to use a potentially hazardous substance like benzene safely and effectively to produce materials that we need and want. We can manage hazardous substances through a combination of:

- understanding the properties of materials;
- using careful and clever design and process engineering;
- placing personal safety and environmental protection as the top priority; and
- enforcing effective regulations.

## Chemistry-Related Careers

Our society is so dependent on chemicals that it's not surprising that many different careers involve chemistry. The most obvious ones are chemical engineers and chemistry teachers. But many others require some knowledge of the use and handling of chemicals. Two examples are food technologist and cosmetics formulator.

### Minds On ... Chemistry Careers in Your Community

With your class, brainstorm a list of careers in your community that involve chemistry of any kind. These could include pharmacist and doctor, but also hair stylist, photocopier repair person, and farmer, among many others.

After you've created the class list, your teacher will assign one of these careers to your group. With your group, research the following questions. If possible, interview someone who has this career.

1. What are some typical examples of how chemistry is used in this career?
2. What training is needed for this career?
3. How many people in your community are working in this career?

Prepare a poster or pamphlet about the career and discuss it with your class.



**FIGURE A2.38** Analysis and development of different food products require a detailed knowledge of food chemistry.

### Food Technologist

Could you tell the difference between red ketchup and green ketchup in a blind taste test (Figure A2.38)? Does ketchup have nutritional value or is it simply for making food more appetizing to some people? Food technologists use sight, smell, touch, and taste to evaluate existing food products and develop new ones. They study how ingredients, which provide nutrition, interact with additives, which improve colour, texture, taste, and shelf life.

In Alberta, the food production, processing, and distribution sector accounts for over one quarter of all jobs. It is second only to the petrochemicals industry in economic importance. Food science is involved in every part of it.

## Cosmetics Formulator

A cosmetics formulator takes raw materials approved for use in the cosmetics industry and combines them to make new products or improve existing ones. Nail polish, lipstick, hair conditioner, and skin cleansers are all mixtures put together under the direction of a cosmetics formulator.

The formulator must have an excellent understanding of the basic properties of the materials and their effects on different parts of the body. For example, a substance that can be safely applied to a fingernail is not necessarily safe to apply to the lips. No less important is an understanding of how different materials interact when mixed. Do they react to produce a toxic substance? Will they stay mixed in a container, even when exposed to higher temperatures and humidity?

Designing a new product is only the first step. The formulator must make sure the product can be made on an industrial scale. The raw materials must be made correctly and consistently so that the final product will always have the right properties. The formulator performs quality control tests on every batch to ensure that pH, viscosity, colour, fragrance, and other properties meet required standards.

## reSEARCH

Acetone is a chemical used to make plastics, drugs, and other chemicals. You may have used it as a solvent for removing nail polish. Find out how acetone enters the environment and list some of the health effects from moderate and high exposure. How can we protect ourselves and the environment and still use this product? Begin your search at



[www.pearsoned.ca/school/science10](http://www.pearsoned.ca/school/science10)

## Working with Chemistry

You may not know a food technologist or cosmetics formulator, but there are many other careers in your community that involve chemistry in some way. Every day, you encounter people who must know how to use certain chemicals safely in specific applications: nurses, painters, pharmacists, dentists, and hair stylists. Chemistry is an essential part of their careers—and your everyday life.

### A2.5 Check and Reflect

#### Knowledge

1. Describe the hazardous effects of CFCs, including the length of time they can remain in the atmosphere.
2. Why is alcohol considered to be a drug?
3. List some direct chemical effects of excessive use of alcohol.
4. Describe the main effect of nicotine on the body.
5. List four poisonous components of tobacco smoke.

#### Applications

6. Some consumer products are not toxic or hazardous themselves, yet they are

connected with issues around the use of hazardous materials. Why?

7. Give two examples of how a food technologist would apply an understanding of chemistry to a new food product.
8. What skills would a cosmetics formulator need?
9. Choose one career in your community and describe how it involves chemistry in some way.

#### Extension

10. Distinguish between physical dependence and psychological dependence on a drug.

## Section Review

## Knowledge

1. What is an element? About how many elements occur naturally?
2. Explain the terms “period” and “family” as they apply to the periodic table.
3. List the properties (mass, charge, location in an atom) of each of the following: proton, neutron, electron.
4. What is an energy level?
5. What is the maximum number of electrons that can exist in the first three energy levels of an atom?
6. What is meant by atomic number?
7. Use an example to explain what isotopes are.
8. What is mass number?
9. What are valence electrons?
10. What are ions?
11. List some properties that ionic compounds have in common.
12. Explain what an electrolyte is and how an electric current runs through it.
13. What is a precipitate, and what is meant by the term “precipitation”?
14. Use the solubility chart in Table A2.14 on page 57 to help you decide whether the following ionic compounds are slightly soluble or very soluble:
  - a) NaCl
  - b) CuI
  - c) BaS
  - d)  $\text{KMnO}_4$
  - e) ammonium sulfide
  - f) calcium nitrate
  - g) silver acetate
  - h) lead(II) sulfate
15. List some properties that are characteristic of acids.
16. List some properties that are characteristic of bases.
17. What is the pH scale? What pH values correspond to acidic, neutral, and basic solutions?

18. What is meant by neutralization?

## Applications

19. How many electrons do each of the following noble gases have: helium, neon, argon? Are the valence energy levels of these elements completely filled or partially filled? What does this say about their chemical stability?
20. Distinguish between mass number and atomic molar mass. Which one of these is found in the periodic table?
21. Draw an atom that has 10 protons, 11 neutrons, and 10 electrons. Using the periodic table in Figure A2.3 on page 30, identify the element. Label the nucleus, the subatomic particles, and the valence energy level.
22. Two isotopes of aluminium are aluminium-26 and aluminium-27. Explain how these atoms are similar and how they are different by describing their atomic structure.
23. Using the octet rule, decide if each of the following elements will gain or lose electrons to become ions. State how many electrons will be involved in each case:
  - a) sodium
  - b) fluorine
  - c) calcium
  - d) nitrogen
  - e) oxygen
24. Name the following ionic compounds:
 

a) $\text{CsCl}_{(s)}$	g) $\text{Al}_2\text{O}_{3(s)}$
b) $\text{K}_3\text{N}_{(s)}$	h) $\text{AgF}_{(s)}$
c) $\text{Na}_2\text{O}_{(s)}$	i) $\text{FeBr}_{2(s)}$
d) $\text{AlN}_{(s)}$	j) $\text{PbCl}_{4(s)}$
e) $\text{MgS}_{(s)}$	k) $\text{Ni}_2\text{O}_{3(s)}$
f) $\text{Li}_3\text{P}_{(s)}$	l) $\text{AuN}_{(s)}$
25. Name the following ionic compounds:
 

a) $(\text{NH}_4)_2\text{S}_{(s)}$	g) $\text{Pb}(\text{HPO}_4)_{2(s)}$
b) $(\text{NH}_4)_2\text{SO}_{4(s)}$	h) $\text{KMnO}_{4(s)}$
c) $\text{Ca}(\text{NO}_3)_{2(s)}$	i) $\text{Na}_2\text{Cr}_2\text{O}_{7(s)}$
d) $\text{Al}(\text{HCO}_3)_{3(s)}$	j) $\text{Al}(\text{CH}_3\text{COO})_{3(s)}$
e) $\text{Na}_2\text{SiO}_{3(s)}$	k) $\text{Co}(\text{C}_6\text{H}_5\text{COO})_{2(s)}$
f) $\text{Cr}(\text{ClO}_2)_{2(s)}$	l) $\text{NH}_4\text{SCN}_{(s)}$

## Section Review

- 26.** Write the formulas of the following ionic compounds:
- sodium bromide
  - calcium nitride
  - magnesium oxide
  - aluminium chloride
  - rubidium iodide
  - lithium phosphide
  - iron(II) sulfide
  - chromium(II) nitride
  - copper(I) oxide
  - titanium(IV) bromide
  - lead(II) fluoride
  - cobalt(III) nitride
- 27.** Write the formulas of the following ionic compounds:
- lithium carbonate
  - beryllium nitrate
  - sodium phosphate
  - ammonium cyanide
  - sodium hydrogencarbonate
  - aluminium borate
  - manganese(II) perchlorate
  - iron(III) hydroxide
  - copper(II) benzoate
  - gold(III) thiocyanate
  - lead(IV) chromate
  - chromium(III) phosphite
- 28.** Write the name or formula of the following molecular compounds:
- $\text{N}_2\text{O}_{(s)}$
  - $\text{SO}_{3(g)}$
  - $\text{PCl}_{5(g)}$
  - carbon tetrabromide
  - sulfur hexachloride
  - oxygen difluoride
  - $\text{NI}_{3(s)}$
  - $\text{H}_2\text{O}_{(l)}$
  - $\text{NH}_{3(g)}$
  - methane
  - tetraphosphorus decaoxide
  - xenon difluoride
- 29.** Water is a polar molecule. Explain what this means.
- 30.** Explain why ionic solids tend to have high melting points, while molecular solids tend to have low melting points.
- 31.** Name each of the following and indicate whether it is an acid or a base:
- |                          |                                    |
|--------------------------|------------------------------------|
| a) $\text{HF}_{(aq)}$    | e) $\text{NH}_4\text{OH}_{(aq)}$   |
| b) $\text{HNO}_{3(aq)}$  | f) $\text{CH}_3\text{COOH}_{(aq)}$ |
| c) $\text{NaOH}_{(aq)}$  | g) $\text{H}_3\text{PO}_{4(aq)}$   |
| d) $\text{HCOOH}_{(aq)}$ | h) $\text{Ca(OH)}_{2(aq)}$         |
- 32.** List health hazards resulting from a sudden intake of an excessive amount of alcohol (alcohol poisoning).
- 33.** List health hazards resulting from the long-term use of tobacco products.
- 34.** Choose one of the following careers and explain why it can be considered a chemistry-related career: doctor, school janitor, car mechanic, cancer researcher.

## Extensions

- 35.** Draw a sketch showing the arrangement of protons, neutrons, and electrons for the following:
- calcium-41 atom
  - calcium-41 ion
- 36.** Write the name or the formula for the following compounds. Both ionic and molecular compounds are listed.
- calcium nitrate
  - aluminium hydroxide
  - methanol
  - phosphorus tribromide
  - $(\text{NH}_4)_2\text{CO}_{3(s)}$
  - $\text{SnCl}_{2(g)}$
  - $\text{SnCl}_{2(s)}$
  - $\text{SrCl}_{2(s)}$
  - sodium ethanoate
  - lead(IV) acetate
  - hydrogen peroxide
  - glucose

**Key Concepts**

In this section, you will learn about the following key concepts:

- how chemical substances meet human needs
- evidence of chemical change
- role and need for classification of chemical change
- writing and balancing equations
- law of conservation of mass
- the mole concept

**Learning Outcomes**

When you have completed this section, you will be able to:

- provide examples of household, commercial, and industrial processes that use chemical reactions to produce useful substances and energy
- identify chemical reactions that are significant in societies
- describe the evidence for chemical changes (i.e., energy change, formation of a gas or precipitate, colour or odour change, or change in temperature)
- differentiate between endothermic and exothermic chemical reactions
- classify and identify categories of chemical reactions (i.e., formation (synthesis), decomposition, hydrocarbon combustion, single replacement, double replacement)
- translate word equations to balanced chemical equations and vice versa for chemical reactions that occur in living and non-living systems
- predict the products of formation (synthesis) and decomposition, single and double replacement, and hydrocarbon combustion chemical reactions, when given the reactants
- define the mole as the amount of an element containing  $6.02 \times 10^{23}$  atoms (Avogadro's number) and apply the concept to calculate quantities of substances made of other chemical species
- interpret balanced chemical equations in terms of moles of chemical species, and relate the mole concept to the law of conservation of mass

## Chemical change is a process that involves recombining atoms and energy flows.



**FIGURE A3.1** The space shuttle is driven by two chemical reactions. The main engines use liquid hydrogen and oxygen, and the booster rockets use solid fuel.

The launch of a space shuttle is always dramatic (Figure A3.1). Flames and smoke pour out. The sound of the engines can be heard—and felt—at the viewing stand 5 km away. At the top of the ship, seven astronauts sit in the crew cabin, dependent on the energy unleashed by the violent chemical reactions occurring just below them.

Within the shuttle, liquid oxygen and hydrogen react to produce water. This reaction drives the shuttle's main engines.

The booster rockets are fuelled by a different reaction in what can be described as a “controlled explosion.”

The solid fuel used in the space shuttle booster rockets is a mixture of aluminium metal and ammonium perchlorate. These two substances react chemically when the rocket is ignited. The reaction quickly releases a tremendous amount of heat. It also converts the solid fuel into several products, some of which are gases. This chemical reaction is complicated, but like all reactions, it is a process in which substances change to form different substances with different properties. In this reaction, energy is released. In others, energy is consumed.

In this section, you will learn more about chemical reactions, and use the law of conservation of mass to help you write chemical equations. These equations are concise, meaningful statements that describe chemical change. You will also learn how to predict the outcomes of thousands of chemical reactions simply by looking at the names of the starting materials and following some simple patterns. Finally, you will be introduced to Avogadro's number ( $6.02 \times 10^{23}$ ) and a quantity called the mole, used universally by chemists to measure amounts of chemicals.

## A 3.1 Important Examples of Chemical Change

### infoBIT

Slicing an onion causes your eyes to sting because of a chemical reaction. Slicing ruptures the onion's cells, allowing substances to mix. A gas is produced and reacts with the water in your eyes—producing dilute sulfuric acid!

Chemical change occurs when a substance or substances react in a chemical reaction to create a different substance or substances. The substances that react are called **reactants**, and their reaction produces new substances called **products**. The products have completely different properties from the reactants. Chemical changes are always accompanied by energy flows. These flows of energy into or out of systems drive chemical reactions.

### Minds On ... Energy Flow through Systems



(a) Fireworks



(b) Water on a stove



(c) Baking



(d) A glow stick

FIGURE A3.2

Look at each of the photographs in Figure A3.2. With your partner, consider the questions on the right. Then write a statement about each process, outlining whether it represents a chemical or physical change, and whether energy is absorbed or released.

1. Which of these processes involve a release of energy?
2. Which involve the absorption of energy?
3. Which are chemical changes?
4. Which are physical changes?

Chemical reactions are used in a wide variety of applications. A fast chemical change, such as the sudden release of gases from solids, may be needed to make an explosion. But not all chemical reactions are fast. Chemical reactions can be used both to release energy slowly and to store it, as in a rechargeable dry cell battery. One chemical reaction in the battery releases energy to power a flashlight. The reverse chemical reaction recharges the battery when it has run down. Chemical reactions are also used to make starting material for industrial processes and in manufacturing final products. For example, large amounts of the compound ethylene are produced in Alberta. It is a starting material for many products, including polyethylene, used in sandwich wrap.

Chemical reactions also occur naturally in countless biochemical processes. These include photosynthesis in plants, which produces sugars, and cellular respiration in all living things, which breaks the sugars down again. We will look at examples of different kinds of reactions to illustrate some of the ways our society uses chemistry.

### Reactions That Form Gases

Reactions that form gases can be sudden and dramatic in an explosion, or slow and steady in a rising cake. An explosion occurs when a small amount of solid or liquid converts quickly to a large volume of gas. Although military uses of explosives may be the first to come to mind, most explosions are commercial.